PB84-186857

Summary of Available Portable VOC (Volatile Organic Compound) Detection Instruments

PEDCo-Environmental, Inc., Arlington, TX

Prepared for

Environmental Protection Agency, Washington, DC

Mar 80

U.S. Department of Commerce
National Technical Information Service
NTIS

PB84-186857

United States
Environmental Protection
Agency

Office of General Enforcement
Washington DC 20460

EPA-340/1-80-010
March 1980

Stationary Source Enforcement Series

EPA

Summary of Available Portable VOC Detection Instruments

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NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-340/1-80-010		PB80 186857

4. TITLE AND SUBTITLE	5. REPORT DATE
Summary of Available Portable VOC Detection Instruments	March 1980
	6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Mazen Y. Anastas, Herbert J. Belknap	PN 3570-3-C

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
PEDCo Environmental, Inc. 1006 N. Bowen Road, Suite 201 Arlington, TX 76012	11. CONTRACT/GRANT NO. 68-01-4147 Task Order 120

12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Division of Stationary Source Enforcement U.S. Environmental Protection Agency Washington, DC 20460	Final
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

DSSE Project Officer: John R. Busik, EN-341 (202) 755-2560

16. ABSTRACT

Federal, state, and local enforcement agencies will require accurate, portable, and relatively inexpensive instruments and methods for effective compliance monitoring of volatile organic compound (VOC) emission sources. This report presents the information gathered on the performance characteristics of these instruments and methods. A survey of instrument manufacturers resulted in information on the cost, weight, and performance characteristics of four categories of portable instruments: ionization detectors, infrared detectors, combustibles analyzers, and miscellaneous instruments. Most of the identified instruments are currently used to detect process leaks. With relatively minor modifications, however, many of the instruments could be used to determine compliance.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air pollution	RACT compliance	13B
Measuring instruments	VOC detection	14B
Organic compounds	VOC emissions	07C

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Unlimited	Unclassified	49
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	

EPA Form 2220-1 (9-73)

EPA-340/1-80-010

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Contract No. 68-01-4147
Task No. 120

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of General Enforcement
Division of Stationary Source Enforcement
Washington, DC 20460

March 1980

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CONTENTS

		Page
Tables		iv
Acknowledgment		v
1	Introduction and Summary	1
	Background	1
	Summary of Findings	2
2	Measurement Of VOC	5
	Introduction	5
	Reference Methods	5
	Types Of VOC Detectors	7
	References	10
3	Portable VOC Instruments	12
	Performance Characteristics	12
	Survey of Instrument Manufacturers	12
	Survey Results	22
4	Conclusions and Recommendation	27
	Ionization Detectors	27
	Infrared Detectors	28
	Combustibles Analyzers	29
	Miscellaneous Instruments	29
	Development Plans	29
Appendix - Sources Of VOC		A-1

TABLES

Number		Page
1	Instrument Parameters	13
2	Portable Ionization Detectors	15
3	Portable Infrared Instruments	18
4	Portable Combustibles Analyzers	20

ACKNOWLEDGMENT

This report was prepared under the direction of Thomas C. Ponder, Jr. The project was managed by Mazen Y. Anastas. The principal investigators were Mazen Y. Anastas and Herbert J. Belknap. Task Manager for the U.S. Environmental Protection Agency was Mr. Robert L. King.

SECTION 1

INTRODUCTION AND SUMMARY

BACKGROUND

The U.S. Environmental Protection Agency (EPA) has issued control techniques guidelines (CTG) for a number of sources that emit volatile organic compounds (VOC). These guidelines concern industries that emit significant quantities of air pollutants in oxidant nonattainment areas for National Ambient Air Quality Standards (NAAQS). The industries and appropriate controls are discussed in the Appendix.

Control methodologies described in these documents represent reasonably available control technology (RACT) that can be applied to existing sources. The definition of RACT is the lowest emission limit that a particular source can meet by application of control technology that is reasonably available, considering technological and economic feasibility. Thus, RACT may require technology that has been applied to similar, but not necessarily identical, source categories. The intention is not to require extensive research and development before a given control technology can be applied to the source. This does not, however, preclude requiring a short-term evaluation program to permit the application of a given technology to a particular source; such an effort is an appropriate technology forcing aspect of RACT.

For many VOC sources, the control technologies must be implemented by January 1, 1982. This implies the monitoring of compliance of many sources. In doing so, Federal, state, and local enforcement agencies will require accurate, portable, and relatively inexpensive instruments and methods to determine compliance.

Depending on the industry, VOC emissions may include single compounds or mixtures of compounds. In the latter case, an effective measurement method is difficult to determine. Because of the large number of organic compounds or species that may be present in a given emission (gasoline vapors are a good example), determining individual compounds is difficult and costly. As a result, EPA has adopted Reference Method 25, which measures the organic carbon content of VOC emissions. Total gaseous nonmethane organic compounds (TGNMO) are measured by (1) removal of methane, carbon dioxide, and carbon monoxide from the sample, (2) combustion of organic compounds to carbon dioxide, (3) conversion of the carbon dioxide to methane, and (4) measurement in a flame ionization detector (FID).

The cost of equipment to perform Method 25 is between $10,000 and $20,000, and the method requires well trained personnel for operation and maintenance. The EPA recognizes that for certain sources "alternative" or "screening" methods may be available in lieu of Method 25 for compliance determinations.

Under Contract No. 68-01-4147, Task 120, the Division of Stationary Source Enforcement (DSSE), U.S. EPA, authorized PEDCo Environmental, Inc., to conduct a survey to investigate current instruments available for field-screening VOC emissions. PEDCo investigated the availability of accurate, relatively inexpensive portable instruments and methods of measuring VOC. This report presents the information gathered on performance characteristics of these instruments and the plans reported for future development to reduce instrument costs and widen the applicability of instruments.

SUMMARY OF FINDINGS

PEDCo conducted a survey of instrument manufacturers and obtained information on the cost, weight, and performance characteristics of various instruments. Four categories of portable instruments, classified by principle of operation, are ionization

detectors, infrared detectors, combustibles analyzers, and miscellaneous instruments.

Most of the instruments identified in this survey are currently used to detect process leaks. With relatively minor modifications, however, many of these instruments could be used for determining compliance. Some care should be exercised to select instruments compatible with the particular constituents of the exhaust gas stream. The FID's use a method similar to Method 25.

It is possible that none of these instruments would be compatible with emissions whose chemical composition fluctuates greatly or is unknown. When all components are known, gas chromatograph (GC) separation facilitates measuring individual component concentrations.

The portable ionization detectors, notably FID's, are versatile, accurate, and highly sensitive. The FID's detect organic carbon and are recommended for Method 25 determinations. Costs of currently available models range from $2300 to $5000. Ionization detectors manufactured by HNU Systems, Inc., and Century Systems can be widely applied for detection of leaks from such sources as petroleum refineries and organic chemical manufacturing plants; these models sell for about $3500 with $1000 additional for a GC option. Analytical Instrument Development, Inc., also manufactures FID instruments, which are less portable and slightly more expensive.

Portable infrared (IR) instruments may be used in the determination of single components or hydrocarbon mixtures such as gasoline and naphtha. The determination of mixtures depends upon the incorporation of multiwavelength capability into instruments and the full characterization of components emitted by the source. The costs of available infrared instruments range from $1250 to $6600. The less expensive instruments are usually preset to measure one species only. The more expensive devices have a built-in capability for continuous variation of the wavelength in the IR spectrum.

Combustibles analyzers, as the name implies, measure the concentration of combustible organic compounds in air as a percentage of the lower explosive limit (LEL). They are currently used in leak detection and industrial safety applications and cost from $160 to $1200. The more expensive instruments are more accurate in ranges from 0 to 100 ppm and 0 to 1000 ppm. Their use for monitoring compliance activities will be limited to leak detection.

A few instruments in the miscellaneous category should be studied. Two instruments of potential use in industries involving halogenated hydrocarbons (such as degreasers and drycleaning systems) are a halide detector and an alarm manufactured by Gas Tech. The halide detector can measure concentrations in ranges from 0 to 100 ppm and 0 to 1000 ppm and costs $1125. The alarm, which costs about $400, can be preset to "sound-off" at any concentration from 0 to 100 ppm.

Detector tubes to measure specific organic compounds are available at a cost of $1 to $3 each. They are used in conjunction with a pump, which meters a specified volume of gas sample and costs about $200. The accuracy, precision, and range of the detector tubes have not been established.

The survey of manufacturer development plans to reduce costs or widen the application range of instruments found that manufacturers would rather respond to changes in demand for instruments than anticipate them. Also, a tenfold increase in demand would reduce costs by only 10 to 15 percent.

SECTION 2

MEASUREMENT OF VOC

INTRODUCTION

This section discusses acceptable EPA and other reference methods for VOC emission measurement and outlines the principles of operation of various VOC detectors. No instrument applicable to all sources combines the desired features of accuracy, quick response, portability, and low cost.

Most rules concerning VOC emissions either regulate the volatile organic content of solvents or limit the exhaust volume or mass concentrations, mass emission rates, or control equipment efficiencies.

In many cases total organic carbon must be used as a measure of VOC emissions, because no detector responds quantitatively to the total molecular structure of the mixture. Although several detectors respond to organic compounds, their response may vary widely from compound to compound and may not be proportional to the total organic mass or volume in a mixture.

REFERENCE METHODS

Several reference methods for the determination of single components or TGNMO in emissions are described below.

Reference Method 25

Reference Method 25 measures TGNMO as organic carbon.[1] It requires the separation of nonmethane organics from other carbon compounds, combustion of organics to carbon dioxide, conversion of carbon dioxide to methane, and analysis of methane by a flame ionization detector. This method has been employed in

Los Angeles County for many years and is considered valid and effective for compliance determinations.[2]

The performance characteristics of Method 25 are as follows:[3]

Accuracy: ± 10 percent
Precision: ± 5 percent
Minimum detectable concentration: 10 ppm
Range: 10 ppm to 2 percent by volume
Portability: Sampling apparatus is portable; sample must be analyzed in laboratory
Equipment cost: $20,000

A commercially available instrument for the measurement of TGNMO by Method 25 is manufactured by Byron Instruments, Inc., Raleigh, North Carolina.[4] The Model 401 hydrocarbon analyzer chromatographically isolates TGNMO from methane, carbon monoxide, and carbon dioxide; oxidizes TGNMO to carbon dioxide; reduces carbon dioxide to methane; and measures the methane in an FID. The estimated performance characteristics of this instrument are as follows:[3,4]

Accuracy: Unknown
Precision: ± 2 percent
Minimum detectable concentration: 1 ppm
Range: 1 ppm to 5 percent
Response time: 10 min
Portability: Semiportable at 60 lb
Cost: $10,000

Other Reference Methods

Other EPA reference methods can detect and measure some organic species. The EPA test methods for vinyl chloride (Method 106) and benzene (Method 110) have been published. A New Source Performance Standards test method (Method 23) for halogenated compounds (perchloroethylene, carbon tetrachloride, ethylene dichloride, trichloroethylene, methylene chloride, 1,1,1-trichloroethane, and trichlorotrifluoroethane) has also been published. All these methods involve collection of a gas sample containing VOC in a plastic bag. The VOC concentration in the sample is determined by gas chromatograph with an FID.

TYPES OF VOC DETECTORS

The U.S. EPA recognizes that alternative methods may be used in lieu of reference methods for determination of compliance by certain sources. For example, an FID may be used where a single component is present. Screening methods may also be used in certain situations despite their lack of precision. A hot wire detector, although not precise, can find gross leaks. The following types of VOC detectors are discussed:

Flame ionization detector
Photoionization (ultraviolet) detector
Nondispersive infrared detector
Thermal conductivity detector
Hot wire detector

Flame Ionization Detector

In an FID, the sample is introduced into a hydrogen flame.[5] The combination of even 0.1 ppm of a hydrocarbon produces measurable ionization, which is a function of the number of carbon ions present. A positively charged collector surrounds the flame, and the ion current between the flame and the collector is measured electronically. Pure hydrogen burning in air produces very little ionization, so background effects are essentially masked by the hydrogen flame. The calibrated output current is read on a panel meter or chart recorder.

Organic compounds containing nitrogen, oxygen, or halogen atoms give a reduced response. The FID hydrocarbon analyzers are usually calibrated in terms of a gas such as methane or hexane, and the output is read in parts per million of carbon measured as methane or hexane.

Although nitrogen (N_2), carbon monoxide (CO), and carbon dioxide (CO_2) do not produce interferences, FID's show a very low sensitivity to water vapor (H_2O). Condensed water vapor can block the sample entry tube and cause erratic readings. Also, when oxygen exceeds 4 percent, a significantly lower output reading can occur. The relative response of the FID to various

organic compounds, including those with attached oxygen, chlorine, and nitrogen atoms, varies from compound to compound.

Photoionization Detector

Photoionization is the process where ultraviolet light ionizes a molecule as follows: $R + h\nu \rightarrow R^+ + e^-$ where R^+ is the ionized species and hv represents a photon with energy less than or equal to the ionization potential of the molecule.[6] All species with an ionization potential less than 10 electron volts (eV) are detected. Because the ionization potential of all major components of air [oxygen (O_2), N_2, CO, CO_2, and H_2O] is greater than 10 eV, they are not detected.

The sensor consists of an argon-filled, ultraviolet (UV) light source that emits photons. A chamber adjacent to the sensor contains a pair of electrodes. When a positive potential is applied to one electrode, the field created drives any ions formed by the absorption of UV light to the collector electrode, where the current (proportional to the concentration) is measured.

Nondispersive Infrared Detector

Nondispersive infrared (NDIR) spectrometry is a technique based upon the broadband absorption characteristics of certain gases. Infrared radiation is typically directed through two separate absorption cells: a reference cell and a sample cell. The sealed reference cell is filled with nonabsorbing gas, such as nitrogen or argon. The sample cell is physically identical to the reference cell and receives a continuous stream of the gas being analyzed. When a particular hydrocarbon is present, the IR absorption is proportional to the molecular concentration of that gas. The detector consists of a double chamber separated by an impermeable diaphragm. Radiant energy passing through the two absorption cells heats the two portions of the detector chamber differentially. The pressure difference causes the diaphragm between the cells to distend and vary a capacitor. The variation

in capacitance is proportional to the concentration of the component of gas present and is measured electronically.

The NDIR instruments are usually subject to interference, because other gases (e.g., H_2O and CO_2) absorb at the wavelength of the gas of interest. Efforts to eliminate the interferences by use of reference cells or optical filters are only partially successsful. For hydrocarbon (HC) monitoring, the detector is filled with one or several different hydrocarbons, which may be different from the HC contained in the sample; this causes a disproportionate response. Other sources of errors include gas leaks in detector and reference cells, inaccurate zero and span gases, nonlinear response, and electronic drift.

Thermal Conductivity Detector

The thermal conductivity of a gas provides a physical method of quantitative measurement.[7] The method is nonspecific, however, for a mixture of gases. When mixtures can be resolved into components, as in a chromatographic column, thermal conductivity is used extensively. For a mixture of a few components in which one gas with a high coefficient of thermal conductivity is highly concentrated, thermal conductivity can also be used with some success. Often, differential measurement can eliminate the influence of other gases, so that a change in concentration of the gas of interest can be detected. If a combustible hydrocarbon is burned in air, the carbon dioxide concentration can be measured before and after combustion, and the change in carbon dioxide is related to the hydrocarbon content. In applying this technique, one must consider the increased water vapor as a product of combustion. It can be accounted for by drying or saturating the sampled air stream before and after combustion. Although the solubility of carbon dioxide in water is low, such a procedure at very low hydrocarbon concentrations can present additional problems.

Hot Wire Detector

The heat of combustion of a gas is sometimes used for quantitative detection of that gas. Suffering the same limitation as thermal conductivity, this method is nonspecific and depends upon sampling and measurement conditions to give satisfactory results.

One type of thermal combustion cell uses a resistance bridge in which the arms of the bridge are heated filaments. The combustible gas is ignited in a gas cell upon contact with a heated filament, and the resulting heat release changes the filament resistance, which is easily measured and related to the gas concentration.

Another combustion method uses catalytic heated filaments or oxidation catalysts. Filament temperature or resistance change is measured and related to gas concentration.

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SECTION 3

PORTABLE VOC INSTRUMENTS

PEDCo conducted a survey to obtain information about performance characteristics and costs of portable VOC instruments, and several instrument manufacturers provided literature describing their instruments. PEDCo telephoned the manufacturers of the more promising instruments to determine their current and future development activities to reduce costs and develop new applications. The results of the survey are summarized below.

PERFORMANCE CHARACTERISTICS

Before surveying instrument manufacturers, PEDCo defined instrument parameters and performance specifications of interest for this task. Based on consultation with in-house personnel who are familiar with the operation and capabilities of various monitoring instruments, PEDCo compiled Table 1, a list of instrument parameters that are necessary for a complete description of the instruments. From this list, PEDCo developed a survey form to help summarize data and identify gaps in information.

SURVEY OF INSTRUMENT MANUFACTURERS

Tables 2, 3, and 4 list the instrument manufacturers most likely to offer portable ionization detectors, infrared instruments, and combustibles analyzers. Sources of information included: "Analytical Chemistry," October 1978; "Thomas Register" for 1978; "Pollution Equipment News," April 1979; the exhibitor listing for the 1979 Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy; and the fifth edition of "Air Sampling Instruments for Evaluation of Atmospheric Contaminants,"

TABLE 1. INSTRUMENT PARAMETERS

Class - Portable: Instrument can be readily transported for field use.

Principle of Operation - The technique used to detect and measure the pollutant or parameter.

Lower Detectable Limit - The smallest quantity or concentration of a sample that causes a response equal to twice the noise level. (Not to be confused with sensitivity, which is response per unit of concentration.)

Range - The lower and upper detectable limits. (The lower limit is usually reported as 0.0 ppm. This is somewhat misleading and should be reported as the true lower detectable limit.)

Interferences - Any substance or species causing a deviation of instrument output from the value that would result from the presence of only the pollutant of concern.

Multiparameter Capability - Ability to measure other pollutants or parameters.

Sampling Method - Specified as continuous, semicontinuous, or intermittent.

Accuracy - The difference between the measured value and the true values which has been established by an accepted reference method procedure. In most cases, a value is quoted by the manufacturer, and no description is given to indicate how this value was obtained.

Precision - The degree of variation between repeated measurements of the same concentration.

Noise - Spontaneous deviation from a mean output not caused by input concentration changes (expressed as a percentage of the full scale).

Lag Time - The time interval from a step change in the input concentration at the instrument inlet to the first corresponding change in the instrument output.

Rise Time - The time interval between the initial response and a 90% response (unless otherwise specified) after a step increase in the inlet concentration.

Response Time - The time interval from a step change in the input concentration at the instrument inlet to a reading of 90% (unless otherwise specified) of the ultimate recorded output. This measurement is the same as the sum of lag time and rise time.

(continued)

TABLE 1. (continued)

Fall Time - The time interval between the initial response and a 90% response (unless otherwise specified) after a step decrease in the inlet concentration. This measurement is usually, but not necessarily, the same as the rise time.

Zero Drift - The change with time in instrument output over a stated time period of unadjusted continuous operation when the input concentration is zero (expressed as a percentage of the full scale).

Span Drift - The change with time in instrument output over a stated time period of unadjusted continuous operation when the input concentration is a stated value other than zero (expressed as a percentage of the full scale).

Ambient Temperature Range - The range of ambient temperature over which the instrument meets stated performance specifications.

Calibration - The method for determining the instrument response to calibration gases (dynamic calibration) or artificial stimuli (static calibration).

Warmup Time - The elapsed time necessary after startup for the instrument to meet stated performance specifications when the instrument has been shut down for at least 24 hours.

TABLE 2. PORTABLE IONIZATION DETECTORS

Manufacturer	Model No.	Pollutant(s) detected	Principle of operation	Cost, $	Weight, lb	Range, ppm	Accuracy, %	Sensitivity	Precision, %	Response time, s	Noise	Ambient temperature, °C	Drift[a]
Analytical Instrument Development, Inc., Avondale, Pennsylvania	550[b] and 551	Nonmethane total hydrocarbons	FID	3711	16.5	0-200 and 0-2000 for Model 550; 0-200 and 0-10,000, for Model 551	±3	0.1 ppm on a scale of 0-200 ppm	±3	5	Less than 0.1 ppm on a 0-200 ppm	0-40	
	555[c]	Total hydrocarbons	FID	3987	20.5	0-10,000, 0-2000, and 0-100	±3	1 ppm on a scale of 0-2000 ppm	±3	5	1 ppm on a scale of 0-2000 ppm	0-40	
	511-12[d]	Total hydrocarbons and individual compounds with GC	FID/GC	4968	41			0.05 ppm as propane				5-45	
Bendix, Environmental and Process Instruments Division, Lewisburg, West Virginia	8401[e]	Total hydrocarbons	FID	3195	40	1-1000	±2	0.01 ppm	±2	8	±1%	5-40	z = ±1% (24) s = ±1% (24)
Century Systems, Arkansas City, Kansas	OVA-118	Total hydrocarbons	FID	3500	12	0-10 and 0-100	±2	0.2 ppm methane	±2	2		-20 to 40	s = ±1% (1)
	OVA-128[f]	Total hydrocarbons	FID/GC	4200	12	0-1000	±2	0.2 ppm methane				-20 to 40	s = ±1% (1)
	OVA-98	Total hydrocarbons	FID	3500	12	0-10,000	±2	0.5 ppm methane	±2	2		-20 to 40	s = ±1% (1)
	OVA-108[g]	Total hydrocarbons	FID/GC	4200	12	0-10,000	±2	0.5 ppm methane				-20 to 40	s = ±1% (1)
General Electric, Instrument Products, Lynn, Massachusetts	TVM-1	Halogenated compounds	Ion capture[h]	4060	23	9 ranges: 0-1 through 0-10,000	±10	0.1 ppm		120		0-55	Negligible
Heath Consultants, Inc., Stoughton, Massachusetts	Detecto-PAK II[i]	Total hydrocarbons	FID	2950	8	0-10 0-100 0-1000	j ±4 j	2 ppm 2 ppm 5 ppm		15		0-50	z = ±1% (7) s = ±4% (7)

(continued)

TABLE 2. (continued)

Manufacturer	Model No.	Pollutant(s) detected	Principle of operation	Cost, $	Weight, lb	Range, ppm	Accuracy, %	Sensitivity	Precision, %	Response time, s	Noise	Ambient temperature, °C	Drift[a]
HNU Systems, Inc., Newton Upper Falls, Massachusetts	PI-101[i]	Chlorinated hydrocarbons, aromatics, aldehydes, ketones, any substance which adsorption of UV light results in ionization	Photoionization	3395	<9	0-20, 0-200, and 0-2000	-7 -7	1 ppm		5		-18 to 50	z = 1% (7) s = 3% (6) for a range of 0-20 ppm; no drift for other ranges
Melroy Labs Springfield, Virginia	HC-500	Total hydrocarbons	FID		40	0-10, 0-50, 0-100, 0-500, and 0-1000	±1 on low scale	0.1 ppm CH_4	±1	45	±0.05 ppm CH_4	10-40	z = 0.2 ppm (24) s = 0.2 ppm (24) for a range of 0-10 ppm
Mine Safety Appliances Co., Pittsburgh, Pennsylvania	Total HC analyzer	Total hydrocarbons	FID	3850	35	0-4 and 0-12,000	±1%			1	±0.5%	4-45	s = 0.5% (24)
Survey and Analysis, Inc. Northboro, Massachusetts	Snifty Model A-500[i]	Total hydrocarbons	FID	1695 for basic unit, $2295 for entire portability package	17	0-10 0-100 0-1000 0-10,000	-55 -35 -3 +20	2 ppm		4		0-50	z = ±20% (7) s = ±12% (7) z = 0 s = ±4% (7) z = ±0.7% (7) s = 0 z = ±0.7% (7) s = 0

(continued)

TABLE 2. (continued)

[a] The letters "z" and "s" indicate zero drift and span drift. The numbers of hours over which drift occurs is given in parenthesis.

[b] A charcoal tube is used to adsorb organics except methane, and a range of 0-10 ppm is available with the recorder. The instrument can be used as alarm by setting in 0-1000 range. This is a screening and leak detection device.

[c] The following features are available: a range of 0-100 ppm with recorder only; internal power, oxygen, and hydrogen supplies; a heated probe; and a battery-operated recorder with a range of 0-100mV d.c.

[d] Capabilities equal or exceed those of Models 550 and 555.

[e] Capabilities to detect higher concentrations require further investigation. This may be suitable for ambient air measurement only.

[f] Optional GC.

[g] Optional GC.

[h] A heated platinum wire embedded in rubidium combusts incoming gases. Combustion of halogenated materials causes electrons to flow from the rubidium. The electrical flow measured is proportional to the amount of halogenated materials present.

[i] Performance characteristics as measured by NIOSH. Reference 6, Section 3.

[j] Inaccurate.

TABLE 3. PORTABLE INFRARED INSTRUMENTS

Manufacturer	Model No.	Pollutant(s) detected	Principle of operation	Cost, $	Weight, lb	Range	Accuracy, %	Sensitivity	Precision, %	Response time, s	Noise, %	Ambient temperature, °C	Drift[a]
Anarad, Inc., Santa Barbara, California	AR-400[b]	Individual species absorbing IR	IR	2395 for an analyzer measuring single gas 5745 for an analyzer measuring three gases (Model 403)			±1		<±1	5		0-49	z = ±1% (24) s = ±1% (24)
Astro Resources Corp., Houston, Texas	5000[c]	Individual hydrocarbons	IR		25	Specified by customer, up to 100%	±1		±1			-40 to 55	z = <±1% s = <±1%
Chrysler Huntsville Electronics Division Huntsville, Alabama	III-C[d]	Total hydrocarbons	IR		20	0-300 and 0-2000 ppm	±2		±2	6		-1 to 46	
	Mopar[d]	Total hydrocarbons	IR		20	0-300 and 0-2000 ppm	±2		±2	6		-1 to 46	
	Atlas[d]	Total hydrocarbons	IR		30	0-300 and 0-2000 ppm	±2		±2	6		-1 to 46	
Foxboro Analytical, Wilks Infrared Center, S. Norwalk, Connecticut	Miran -104[e]	Any species absorbing IR between 2.5 and 14.5 μm in wavelength	IR	Not sold in United States but price may be similar to Miran-1A	24	ppm to percent	±5	1 ppm		1,4,10, and 40		0-46	z = ±0.3% (8)
	Miran-1A	Any species absorbing IR between 2.5 and 14.5 μm in wavelength	IR	6600	32	<ppm to percent	3-4		1-2	1,4,10, and 40	0.3	0-40	z = ±0.2% (8)

(continued)

TABLE 3. (continued)

Manufacturer	Model No.	Pollutant(s) detected	Principle of operation	Cost, $	Weight, lb	Range	Accuracy, %	Sensitivity	Precision, %	Response time, s	Noise, %	Ambient temperature, °C	Drift[a]
Gas Tech, Inc., Mountain View, California	Halide detector	Halogenated hydrocar-	Enhancement of radiation from a spark by halogens	1125	13	0-100 and 0-10,000 ppm				5			
Infrared Industries, Inc., Santa Barbara, California	IR-711	Alkane hydrocarbons	IR (solid state detector)	1250	9	0-100% LEL and 0-1000 ppm	±5		±5	120		0-50	z = ±5% (8)
	IR-702[f]	Any species absorbing IR	IR	2895	34	IR 702, IR 703, and IR 705 are available with analog or digital scales; analog scales range from 0-100% to 0-200 ppm; digital scales range from 0-100% to 0.1%	±1			5		0-50	z = ±1% (24) s = ±1% (24)
	IR-703[f]	Any species absorbing IR	IR	2395	34								
	IR-705[f]	Any species absorbing IR	IR	2950	34								
Mine Safety Appliances Co., Pittsburgh, Pennsylvania	LIRA 303[g]	Hydrocarbon species that absorb IR	IR	2970	37	0-100% LEL and 0-1000 ppm			±1	5	<1	4-45	z = <±1% (24) s = <±1% (24)

[a] The letters "z" and "s" indicate zero drift and span drift. The number of hours over which drift occurs is given in parentheses.

[b] Available in single and dual component versions.

[c] Factory-calibrated for gas to be detected in application.

[d] Autoexhaust analyzers; solid state detectors.

[e] Miran-101 and Miran-103 do not have built-in, multiparameter capabilities. Their measurement range is from 0 to 1000 ppm for most species.

[f] IR-702, IR-703, and IR-705 are usually bench- or panel-mounted instruments. IR-702 is a dual component instrument; and IR-703 and IR-705 are single component instruments.

[g] Can be calibrated to measure a single gas or a mixture if the instrument is panel-mounted.

TABLE 4. PORTABLE COMBUSTIBLES ANALZERS

Manufacturer	Model No.	Pollutant(s) detected	Principle of operation	Cost, $	Weight, lb	Range	Accuracy, %	Sensitivity	Precision, %	Response time, s	Ambient temperature, °C	Drift[a]
Bacharach Instrument Co., Santa Clara, California	G	Combustible gases	Catalytic combustion	253	4	0-100% LEL					0-50	
	L[b]			160	4	0-100% LEL						
	H[b]			279	5	0-100% LEL						
	TLV Sniffer[c]		Catalytic combustion	896	5	0-100, 0-1000, and 0-10,000 ppm	±3	2 ppm	±3			
Biomarine Industries, Inc., Malvern, Pennsylvania	922	Combustible gases and vapors	Catalytic combustion	495	1.5	0-100% LEL	±5% LEL			5	-15 to 40	
	900, 900R, and 900RS	Combustible gases and vapors	Catalytic combustion	685 695, and 715	3	0-100% LEL	±5% LEL			5	-15 to 40	
Control Instruments Corp., Fairfield, New Jersey	FFAP[d]	Flammable gases and vapors	Thermal combustion		28	0-100% LEL	±3		±1	<10	0-52	z = <±5% (1 yr) s = <±5% (1 yr)
Gas Tech, Inc., Mountain View, California	1177	Combustible gases	Catalytic combustion	525	6	0-100% LEL	±5		±2	4	0-40	
	1238	Combustible gases	Catalytic combustion	695	7	0-100% LEL and 0-500 ppm	±2		±2	10	-20 to 50	
International Sensor Technology, Santa Ana, California	AG5100	Combustible gases and vapors	Change in resistance within detector	1200 for ppm scale, 825 for LEL scale		LEL and ppm	±5		±5	10 on LEL scale and 60 on ppm scale		Negligible in a 3-month period
Mine Safety Appliances Company, Pittsburgh, Pennsylvania	20[e]	Combustible gases	Catalytic combustion	374	6	0-100% LEL						
	30[f]	Combustible gases	Catalytic combustion	374		0-100% LEL						
	40[g]	Combustible gases	Catalytic combustion	374		0-10% and 0-100% LEL						

(continued)

TABLE 4. (continued)

Manufacturer	Model No.	Pollutant(s) detected	Principle of operation	Cost, $	Weight, lb	Range	Accuracy, %	Sensitivity	Precision, %	Response time, s	Ambient temperature, °C	Drift[a]
Survey and Analysis, Inc Northboro, Massachusetts	OnMark Model 5[h]	Combustible gases and vapors	Thermal conductivity	285	<5	0-5 and 0-100%	±3		±3	<10	0-50	z = ±4% (2 mo)
Teledyne Analytical Instruments, San Gabriel, California	980	Total combustibles and oxygen	Catalytic combustion		17	Scale: 0-5% methane; others are available	±2	0.5% of full scale		20	0-50	

[a] The letters "z" and "s" indicate zero drift and span drift given as percent of scale over the time specified in parentheses.

[b] Catalytic combustion (hotwire) in low range and thermal conductivity in high range.

[c] The ranges of TLV can be multiplied by 10 with a dilution probe.

[d] The FFAP uses a propane flame to combust sample gas and is fully portable.

[e] Can be factory calibrated for five gases, such as pentane.

[f] Calibrated to measure natural gas and petroleum vapors in air mixtures.

[g] Factory calibrated for pentane.

[h] Filaments for the 0-100% scale are thermal sensors heated to 300° to 400°F, and filaments for the 0-5% scale are catalytic sensors heated to 1200° to 1300°F.

published by the American Conference of Governmental Industrial Hygienists in 1978.

Instrument manufacturers were requested to provide information on portable instruments that are capable of detecting and measuring VOC concentrations from 10 to 10,000 ppm. PEDCo decided that instruments weighing 40 lb or less may be considered portable. Although most manufacturers were responsive to the survey, information received after the initial contact was usually incomplete. Followup contacts were often necessary. After the list of manufacturers was exhausted and the accumulated data were analyzed, manufacturers of apparently promising instruments were again contacted to determine their plans for further development. Specifically, they were asked to project future costs on the basis of order of magnitude increases in demand for their instruments.

SURVEY RESULTS

Four classes of detectors or methods of VOC detection and measurement) were revealed by the survey. These are:

Ionization detectors

Infrared detectors

Combustibles analyzers

Miscellaneous instruments, including detector tubes and intermittent colorimetric methods

Data on performance characteristics, measurement capabilities, and costs are summarized below.

Ionization Detectors

The performance characteristics of ionization detectors are summarized in Table 2. Prominent among these are the FID's, which can measure TGNMO or individual organic compounds. When a GC option is available, the instrument can be used to measure concentrations of various components in a mixture, after calibration curves are obtained for each component.

In general, instruments with FID detectors, are read directly and are more accurate in the range from 0 to 10 ppm than infrared instruments. They do not respond to water vapor, but particulate matter must be removed from the gas sample.

PEDCo found only one photoionization detector (the HNU Systems Model PI-101) that uses ultraviolet light to effect ionization. As with FID's, the detector's response varies with the functional group in the organic species. Although the instrument has been used as a screening device for leak detection in processes involving synthetic organic chemicals, its applicability in compliance determinations, especially when mixtures are involved, is uncertain. The unit is not known to have been used for measuring organic species that had been separated with a GC.

Another ionization instrument detector is the General Electric Model TVM-1 for measurement of halogenated species. Literature about the instrument suggests that combustion of the halogenated organic species results in an electronic flow whose magnitude is proportional to concentration. The manufacturer recommends using the instrument in industrial hygiene applications. Its use, however, in determining VOC emissions from such sources as degreasers and drycleaning systems should be explored, because the detection range suggests suitability to these sources.

The costs of available ionization detectors range from $2300 to $5000. Addition of a GC unit can increase the cost by $1000. The lowest priced FID has been used to detect methane in leaks from pipelines and in sewer gases. The FID's used as screening devices for leak detection in the petroleum and petrochemical industries (such as the Century Systems and HNU Systems instruments) cost about $3500.

Infrared Instruments

Performance characteristics of portable infrared detection devices are summarized in Table 3. These devices are suitable for the detection and measurement of single organic compounds.

The wavelength at which a certain compound absorbs infrared radiation is predetermined, and the device is preset (by the use of optical filters) for that specific wavelength. If set to a wavelength of 3.4 micrometers, infrared devices can be used to detect and measure petroleum fractions, including gasoline and naphtha, which are known to be mixtures of aliphatic (saturated and unsaturated) and aromatic hydrocarbons.

Particulates and water vapor should be removed from VOC gas samples to be measured. Water absorbs IR radiation over the entire spectrum. The IR devices can be used to determine TGNMO in mixtures by setting the device to one component if the relative concentrations of the constitutents do not vary or by changing the setting of the wavelength to accommodate each component.

The costs of available IR detection devices range from $1250 to $6600. The less expensive instruments (such as the Infrared Industries Model IR-711) do not offer built-in multiparameter capabilities and require calibration at the factory. The more expensive devices (such as the Foxboro-Wilks Model Miran-1A) offer multiparameter capabilities and can measure a wider range of concentrations.

Combustibles Analyzers

Performance characteristics and capabilities of combustibles analyzers are summarized in Table 4. With few exceptions, these instruments measure VOC concentration as a percentage of the LEL of combustible hydrocarbons; the LEL is generally on the order of 10,000 ppm.

Currently, these analyzers are used in leak detection and explosion-safety applications. The detectors are nonspecific, and with the exception of the Bacharach Model TLV Sniffer and International Sensor Technology Model AG5100, their accuracy in the range from 0 to 100 ppm is questionable.

The costs of these instruments vary from $160 to $1200. More expensive units can measure concentrations in ranges from 0 to 1000 ppm and 0 to 100 ppm.

Miscellaneous Instruments

PEDCo found other instruments that may be useful in compliance determination for various sources of VOC. For example, Gas Tech, Inc., of Mountain View, California, offers two commercially available devices for detection of halogenated hydrocarbons. The first, called Halide Detector, operates on the principle of enhancement of UV radiation emitted from a spark in the presence of halogenated species. This instrument weighs 13 lb, costs $1125, and has concentration ranges of 0 to 100 ppm and 0 to 10,000 ppm. Another instrument offered by the same manufacturer acts as an alarm for the presence of halogenated species at preset concentration levels in the range of 0 to 100 ppm; the alarm costs $400.

A number of potentially useful methods can measure individual organic species at concentrations below or at the threshold limit value (TLV) and up to several thousand parts per million, depending on species. These methods involve passing a gas sample of known volume through a small glass detector tube. The tube is packed with a sorbent that has been impregnated with a chemical reagent known to produce a coloration or stain in the presence of the organic species of interest. The length of stain or coloration produced indicates the concentration, and calibration charts that relate stain length to concentration are provided.

Detector tubes certified by the National Institute for Occupational Safety and Health are sold in packages of 10 tubes at a cost between $13 and $30 per package, depending on species to be measured. The pumps used to meter known volumes of gas through the tube usually cost about $200. Two manufacturers of detector tubes and pumps are Mine Safety Appliances and National Draeger, Inc.; both firms are in Pittsburgh, Pennsylvania.

The accuracy of detector tubes is about ±25 percent at five times TLV and ±35 percent at one-half TLV. The precision ranges from 10 to 15 percent, but is difficult to quantify because of

variations among different batches of detector tubes. The potential use of detector tubes to determine VOC compliance would be restricted to situations where regulations limit the concentration of a given species (e.g., perchloroethylene drycleaning, where a limit of 100 ppm is specified).

Safety Certification

Portable instruments to detect VOC emissions from stationary sources may be used in hazardous locations such as petroleum refineries and bulk gasoline terminals. The National Electrical Code requires that instruments to be used in hazardous locations be certified to be explosion proof, intrinsically safe, or purged.

Hazardous locations are divided into three classes: Class I, Class II, and Class III. Each class has two divisions (Division 1 or 2) according to the probability that a hazardous atmosphere will be present; and also into seven groups depending on the type of hazardous material exposure. Groups A through D are flammable gases or vapors, and Groups E, F, and G apply to combustible or conducting dusts. Class I, Division 1, Groups A, B, C, and D locations are those in which hazardous concentrations of flammable gases or vapors may exist under normal operating conditions. Class I, Division 2, Groups A, B, C, and D locations are those in which hazardous concentrations of flammables may exist only under unlikely conditions of operation.

Only five manufacturers produce certified portable VOC detection instruments. Table 5 lists these manufacturers, approved instrument model numbers, and instrument certification categories.

TABLE 5. PORTABLE VOC DETECTION INSTRUMENT CERTIFICATION

Manufacturer	Model No.	Certification
Bacharach Instrument Co., Santa Clara, California	L	Intrinsically safe, Class I, Division 1, Groups C & D
	TLV Sniffer	Intrinsically safe, Class I, Division 1, Groups C & D, and Class I, Division 2, Groups A & B
Century Systems, Arkansas City, Kansas	OVA-128	Intrinsically safe, Class I, Division 1, Groups A, B, C, & D
	OVA-108	Intrinsically safe, Class I, Division 1, Groups A, B, C, & D
HNU Systems, Inc. Newton Upper Falls, Massachusetts	PI-101	Intrinsically safe, Class I, Division 2, Groups A, B, C, & D
Mine Safety Appliances Co., Pittsburgh, Pennsylvania	40	Intrinsically safe, Class I, Division 1, Group D, and Class I, Division 2, Groups A, B, & C
Survey and Analysis, Inc., Northboro, Massachusetts	OnMark Model 5	Intrinsically safe, Class I, Division 1, Groups A, B, C, & D

SECTION 4

CONCLUSIONS AND RECOMMENDATION

Of the four classes of VOC detectors described in the last section, ionization detectors appear (1) the most versatile in terms of applicability to various sources of VOC, (2) the most accurate, especially in the lower ranges (0 to 10 ppm) of concentration, and (3) the most sensitive, both in terms of minimum detectable limit and instrument response per unit change of concentration in the lower concentration range. This section examines the applicability of each instrument class in VOC compliance monitoring.

IONIZATION DETECTORS

Ionization detectors, notably FID's, are applicable to nearly all sources of VOC. Although most current models are mainly used to detect hydrocarbon leaks in petroleum refineries, petrochemical plants, etc., they can be modified to measure VOC control device efficiencies, source emission concentrations, and fugitive emissions.

As a result of their capability to detect organic carbon, ionization detectors may be used to determine mixtures as well as individual components. If the individual species in a mixture are known, the components can be separated in a GC column, and the detector can be calibrated for those species.

For a single component a GC is usually not necessary. VOC sources with a single component include perc drycleaning systems and degreasers.

Available ionization detectors can require modifications to improve their capabilities for extractive sampling from stacks,

vents, and ducts. These modifications may include provisions for removal of particulates and heating of sampling probe and line to prevent loss of the sample through condensation.

Ionization detectors are not suitable to determine the compliance of sources with a control device (such as a fume incinerator) that chemically alters emission species. In such cases, Reference Method 25 should be used to measure organic carbon.

INFRARED DETECTORS

As mentioned earlier, infrared detectors are suitable for application when only a single component is present or when emissions consist of petroleum fractions (such as naphtha and gasoline) in the vapor phase. The less expensive devices are calibrated for one component at the factory or can use optical filters to change the wavelength. The more expensive devices can continuously vary wavelength over the useful infrared spectrum.

Where infrared devices are used in extractive sampling of stacks and vents, provisions should be made for the removal of particulates and moisture. The latter absorbs radiation over the entire spectrum.

Infrared devices can be used to determine compliance of surface coating operations if a single-component coating is used or if the devices offer multiparameter capabilities and all coating components are known. These instruments can also be used to monitor bulk gasoline plants, petroleum liquids storage facilities, tank truck gasoline terminals, perc drycleaning plants, solvent metal cleaning operations, pharmaceutical plants, and pneumatic tire manufacturers.

The minimum detectable limit of many infrared devices ranges from a few parts per million to 100 ppm, depending on species and path length of the detectors.

COMBUSTIBLES ANALYZERS

Combustibles analyzers are mostly used to detect leaks and monitor LEL percentages. Potential uses in leak detection are in refineries and facilities for petroleum liquids storage and loading. Applications involving the measurement of LEL percentages include surface coating operations, graphic arts, and refineries.

In surface coating operations that operate spray booths and bake ovens in the range of 10 to 25 percent LEL, the accuracy of these devices can be sufficient for control and maintenance of this level of combustibles. In their present state of development, however, combustibles analyzers cannot be used to determine compliance because they offer no reliable methods of data interpretation in terms of organic carbon and because (with the exception of the Bacharach Model TLV Sniffer) their accuracy in ranges from 0 to 100 ppm and 0 to 1000 ppm is in doubt.

MISCELLANEOUS INSTRUMENTS

Detector tubes with proven accuracy and precision can be used to determine compliance if the organic species is known. Their applicability may be limited by the recommended concentration range in which they can be used.

DEVELOPMENT PLANS

After completing the initial survey, PEDCo contacted a selected number of instrument manufacturers to obtain information on their plans for further development. Specifically, PEDCo asked the following questions:

> Are there plans for further development of currently available models in order to reduce cost and improve capabilities?
>
> What reductions in costs (if any) can be anticipated if demand increases tenfold?

What are the current and projected applications of the available instruments in the monitoring of emissions from sources of VOC?

In general, instrument manufacturers were reluctant to develop further capabilities and applications of their instruments before a clearly positive demand develops. One manufacturer currently plans to develop another portable photoionization (ultraviolet) detector, and another is developing temperature controls for the GC column in a GC/FID instrument.

Approximately one-third of the manufacturers contacted mentioned that a fivefold to tenfold increase in demand would reduce the costs of their instruments by 10 to 15 percent. Many said they would not reduce costs for such increases in demand, and others could not provide answers.

APPENDIX

SOURCES OF VOC

SOURCES OF VOC

SOURCES AND EMISSIONS - GENERAL

As of November 1979, CTG documents covering the following industries and activities had been issued:[1-21]

1. Surface coating of cans, coils, paper, fabrics, automobiles, and light-duty trucks
2. Surface coating of metal furniture
3. Surface coating of insulation of magnet wire
4. Surface coating of large appliances
5. Surface coating of miscellaneous metal parts and products
6. Factory surface coating of flat wood paneling
7. Graphic arts--rotogravure and flexography
8. Bulk gasoline plants
9. Storage of petroleum liquids in fixed roof tanks
10. Tank truck gasoline loading terminals
11. Refinery vacuum producing systems, wastewater separators, and process unit turnarounds
12. Use of cutback asphalt
13. Gasoline service stations
14. Leaks from petroleum refinery equipment
15. Manufacture of vegetable oils
16. Petroleum liquid storage in external floating roof tanks

17. Perchloroethylene drycleaning systems

18. Gasoline tank trucks and vapor collection systems

19. Solvent metal cleaning

20. Manufacture of synthesized pharmaceutical products

21. Manufacture of pneumatic rubber tires

The first six industries are coating operations in which surfaces are cleaned and dried before single or multiple coatings are applied. Coatings can be applied by dipping, flowcoating, or electrostatic spraying. After each coating is applied, the parts may go through a flash tunnel to allow the coating to flow out properly and through a bake oven to cure the coating. The applied coatings are usually polymers, such as polyesters and epoxy resins, and their application requires the use of solvents as thinners to reduce viscosity. The solvents used can consist of a single component or a mixture of aliphatic and aromatic hydrocarbons, ketones, esters, and alcohols. Many of the solvent mixtures form explosive mixtures with air upon evaporation from the coated parts in such process equipment as spray booths, flashoff tunnels, and bake ovens. Fire insurance underwriters require that the concentration of combustibles be maintained below 25 percent LEL unless adequate LEL monitoring equipment is used (in which case 50 percent LEL is allowed).

Many spray booths, bake ovens, etc. are operated in the range from 5 to 15 percent LEL to prevent leakage of vapors into the work area. Also, in spray booths where worker exposure is likely, the LEL is maintained at or below 1 percent. As a rule-of-thumb, 100 percent LEL results from the evaporation of 1 gallon of solvent in 2500 standard cubic feet of air.[22] Depending on molecular weight and density, this may result in a concentration of about 10,000 parts per million by volume (ppmv).

Emission reduction alternatives for surface coating operations include (1) the substitution of powder, water borne, or high-solids coatings, (2) the use of activated carbon adsorption

to control emissions from application and flashoff areas when conventional solvents are used, and (3) the use of fume incineration for reduction of emissions from bake ovens. A typical regulation limits emissions to 0.36 kilograms VOC/liter (3.0 lb VOC/gal) of coating applied.

When control devices such as activated carbon adsorbers or fume incinerators are used, the regulations may specify the efficiency (80 to 95 percent) at which the device should be operated.

Hydrocarbon emissions from bulk gasoline plants result from filling of trucks and storage tanks and breathing and drainage losses from storage tanks. Control alternatives include the utilization of submerged filling and vapor balance systems. Compliance monitoring would consist of onsite inspections to ensure that proper operating procedures are implemented.

Hydrocarbon emissions from fixed-roof tanks may be controlled by installing internal floating roofs.

Hydrocarbon emissions from tank truck gasoline loading terminals result from filling of tank trucks and from leaks in pumps and pipe fittings. Vapor recovery or combustion devices can be used to control emissions from filling operations.

Control of emissions from refinery vacuum producing systems, wastewater separators, and process unit turnarounds usually involves modifying the operating procedures or changing the process so that hydrocarbon emissions from the various sources are manifolded to the refinery flare system.

The VOC emissions from the use of cutback asphalt can be controlled by substitution of emulsified asphalt involving only water and an organic emulsifier.

Emissions of halogenated hydrocarbons from solvent metal cleaning operations can be controlled by implementing operating procedures that minimize solvent loss and by retrofitting control systems, such as carbon adsorbers and freeboard chillers.

In September 1979, the EPA issued a guidance document to state and local agencies that contained model regulations affecting nine industries and activities.[23] Table A-1 summarizes

TABLE A-1. CONTROL OF VOC EMISSIONS FROM STATIONARY SOURCES

Industry	Source	Pollutant species	Uncontrolled concentration, ppm	Controlled concentration	Control method	Stream pressure	Stream temperature
Petroleum refinery equipment	Leaks from pipe connections, valves, pump seals, etc.	Hydrocarbons	>10,000	Negligible	Repair leak immediately		Ambient
	Same as above	Hydrocarbons	>10,000	Negligible	Repair leaks during shut down		Ambient
Surface coating of miscellaneous metal parts	Spray coating, flow coating (flashoff)	Ketones, esters, alcohols, aliphatic HC, ethers, aromatic HC, terpenes	100-400[a]	10-100 ppm (60 to 90% reduction)	Waterborne coating	Slightly below atmospheric	Ambient
		Same as above	100-400[a]	5-40 ppm (90% reduction)	Carbon adsorption		Ambient
		Same as above	100-400[a]	90% reduction	Incineration		Ambient
	Ovens	Same as above	100-800[a]	90% reduction	Carbon adsorption		100°-400°F
		Same as above	100-800[a]	90% reduction	Incineration		100°-400°F
Surface coating of flatwood paneling	Coating operations	Ketones, esters, alcohols, hydrocarbons, toluene, xylene	100-300[b]	2.9-5.8 kg per 100 m^2	Afterburner carbon adsorption	Slightly below atmospheric	Ambient

(continued)

TABLE A-1. (continued)

Industry	Source	Pollutant species	Uncontrolled concentration, ppm	Controlled concentration	Control method	Stream pressure	Stream temperature
Synthesized pharmaceutical products manufacture	Reactors	Ethyl acetate, methanol, chloroform, xylene, benzene, heptane, toluene	No data	No data	Condensers, adsorbers, liquid scrubbers, incinerators	Slightly above or below atmospheric	
Pneumatic rubber tire manufacture	Undertread cementing	Heptane, hexane, isopropanol, naphtha, toluene	200-1500[c]	40-300 ppm (80% reduction)	Carbon adsorption or incineration	Atmospheric	65°-85°
	Green tire spraying	Heptane, hexane, toluene	100-1400[c]	10-140 ppm (90% reduction)	Carbon adsorption or incineration	Atmospheric	60°-110°F
	Tread-end cementing	Gasoline, hexane, isopropanol, naphtha, toluene	100-1500[c]	10-150 ppm (90% reduction)	Carbon adsorption or incineration	Atmospheric	60°-70°
	Bead dipping	Same as above	60-1200[c]	6-120 ppm (90% reduction)	Carbon adsorption or incineration	Atmospheric	Ambient
	Tire building	Gasoline, hexane, methanol, naphtha, isopropanol, toluene	3-95[c]		Controls not needed	Atmospheric	Ambient
Graphic arts systems (flexography and rotogravure	Printing rollers	Alcohols, glycols, esters, hydrocarbons, ethers, ketones	500-2400[d]	50% reduction	Waterborne inks	Slightly below atmospheric for all sources	Ambient

(continued)

TABLE A-1. (continued)

Industry	Source	Pollutant species	Uncontrolled concentration, ppm	Controlled concentration	Control method	Stream pressure	Stream temperature
		Same as above	500-2400[d]	75% reduction	Carbon adsorption		Ambient
		Same as above	500-2400[d]	75% reduction	Incineration		Ambient
	Dryers	Same as above	500-1500[d]	75% reduction	Carbon adsorption		100°-400°F
		Same as above	500-1500[d]	75% reduction	Incineration		100°-400°F
Storage tanks with external floating roof	Floating roof seal	Hydrocarbons, including gasoline	Unknown	Negligible	Roof seal		Ambient
Perchloroethylene drycleaning system	Cleaning machine	Perchloroethylene	600-6500[e]	25-100 ppm	Carbon adsorption	Slightly above atmospheric	Ambient to 120°F
	Dryer/reclaimer	Same as above	600-6500[e]	25-100 ppm	Carbon adsorption		Ambient
	Distillation unit vent	Same as above	600-6500[e]	25-100 ppm	Carbon adsorption	Atmospheric	Ambient to 120°F

[a] Reference 23.

[b] Estimated on the basis of data from coating of miscellaneous metal parts.

[c] Reference 21.

[d] Reference 7.

[e] Reference 17.

controlled and uncontrolled VOC emissions from these and other industries. It also shows sources, pollutant species, control methods, and stream pressures and temperatures.

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